



2019 Spacecraft Thermal Control Workshop

# High Performance Thermal Switch for Lunar Night Survival

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**Jet Propulsion Laboratory**  
California Institute of Technology

Approved for Unlimited Release

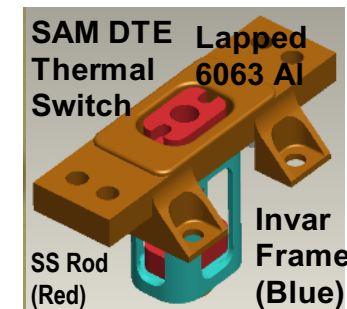


# Outline

- Introduction ... *objective, approach, results*
- Background ... *related device development history*
- Concept ... *basis of operation for invention*
- Design ... *layout, materials, dimensions*
- Fabrication ... *key build processes/techniques*
- Testing ... *qualification test program to TRL6*
- Conclusion ... *implications for flight implementation*

# Introduction

- **OBJECTIVE:** To enable future NASA/JPL solar/battery (non-radioisotope, night-survivable) lunar instruments, the development goal was a thermal switch that would outperform the **100:1** MER paraffin thermal switch by at least 10X
- **APPROACH:** Utilize differential thermal expansion (DTE) but **reverse** the operation of **normal-operation** DTE thermal switches (e.g., those for the Curiosity SAM instrument, cryocooler redundancy) that are OFF/warm, ON/cold ... **lunar instrument need:** ON/warm, OFF/cold
- **RESULTS:** Two reverse-operation DTE thermal switch prototypes were built as illustrated in graphic to the right; these units have a measured  $G_{ON} = 5 \text{ W/K}$ ,  $G_{OFF} = 0.002 \text{ W/K}$ ,  $G_{ON}/G_{OFF}$  ratio of **2500:1 ... 25X MER Thermal Switch!!** This briefing describes their development and qualification to TRL6



JPL Reverse-Operation  
DTE Thermal Switch  
*Fully Autonomous*  
*Patent-Pending*



<b>Body:</b> Aluminum	Alum/Ultem 1000
<b>Rod:</b> Invar/Ultem 2300	Invar/Ultem 2300



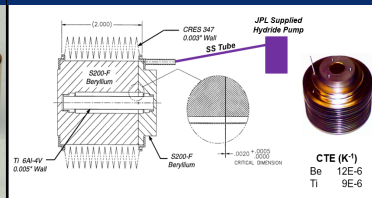
# Background

**Evolution/History:** *conical gas-gap* → *flat gas-gap* → *normal-operation DTE* → *reverse-operation DTE*. As a result, JPL is developing the LITMUS dual thermally switched nested enclosure concept for lunar night survival.

**1997**  
**Conical Gas-Gap: Cu/SS**



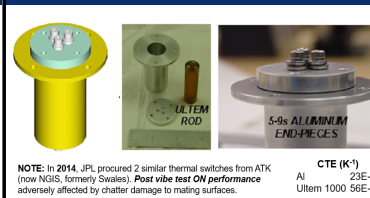
**1998**  
**Flat Gas-Gap: Be/Ti/SS**



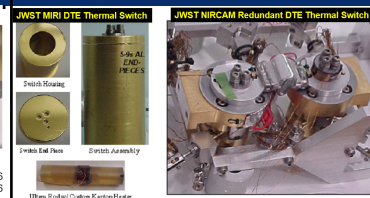
**1999**  
**Normal DTE: Be/SS**



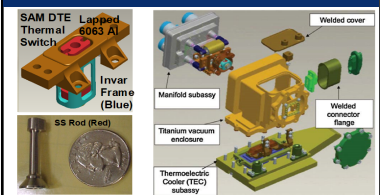
**2001**  
**Normal DTE: Al/Ultem**



**2003 ... JWST**  
**Normal DTE: Al/Ultem**

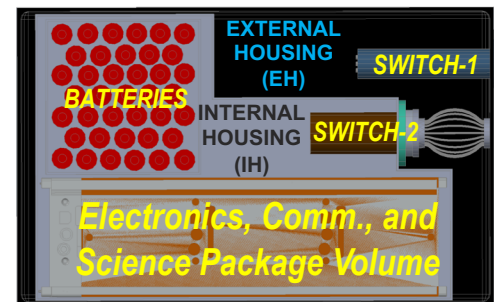
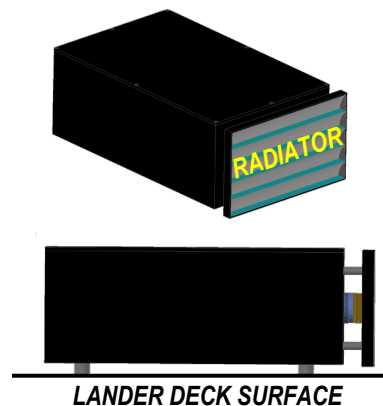


**2012 ... SAM Flight**  
**Normal DTE: Al/SS/Invar**



**2018 - 2019**  
**Reverse-Operation DTE: JPL Lunar Instrument Thermal Management Ultra-Isolation System (LITMUS)**

**LITMUS** is a dual thermally switched internal/external housing (IH/EH) concept for solar/battery powered lunar instruments.



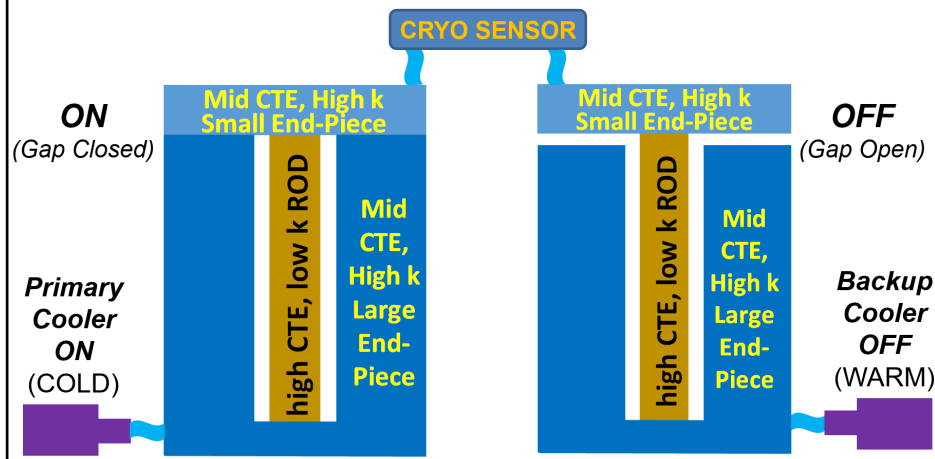


# Concept

DTE thermal switch actuation due to the mating/de-mating of parallel, flat, near mirror finish metal surfaces. Motion caused by DTE of mid-CTE, high k metal end-pieces vs. high-CTE (normal) or low-CTE (reverse), low k rod.

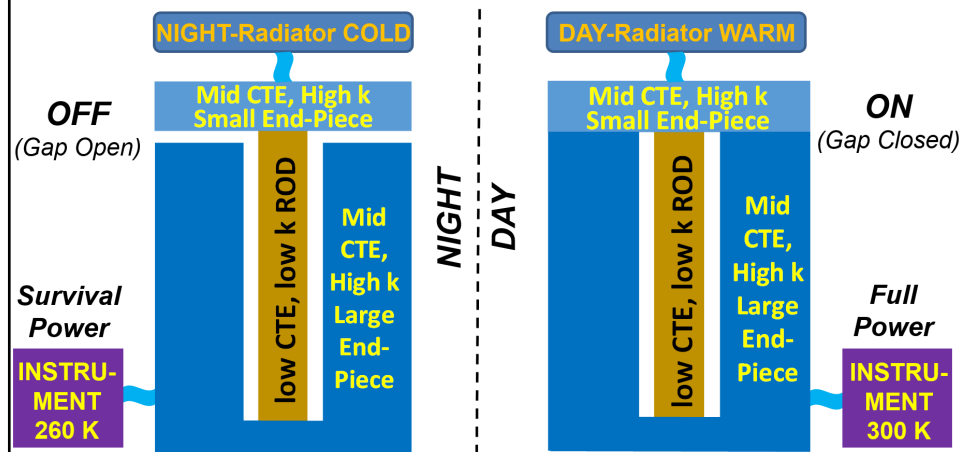
## Normal-Operation

For applications that must **KEEP HEAT OUT**, such as a dual cryocooler system or Curiosity SAM, a **Normal-Operation DTE Thermal Switch** has a LOW k ROD with a **Higher CTE** than the HIGH k END-PIECES.



## Reverse-Operation

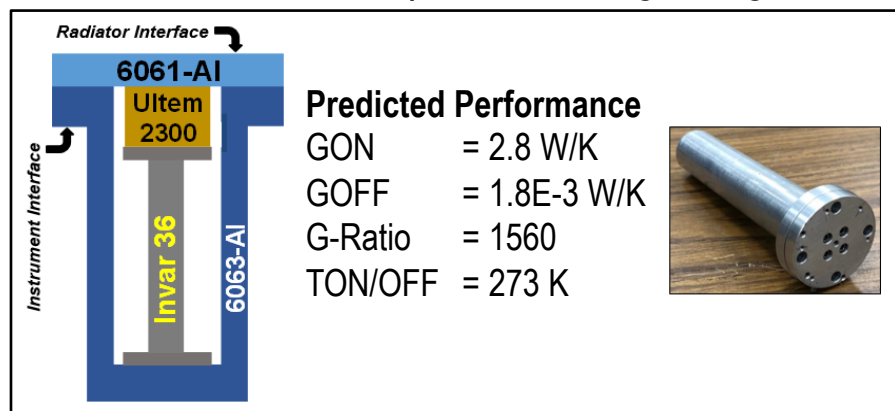
For applications that must **KEEP HEAT IN**, such as lunar instruments, the new JPL-Developed **Reverse-Operation DTE Thermal Switch** needs a LOW k ROD with a **Lower CTE** than the HIGH k END-PIECES.



# Design

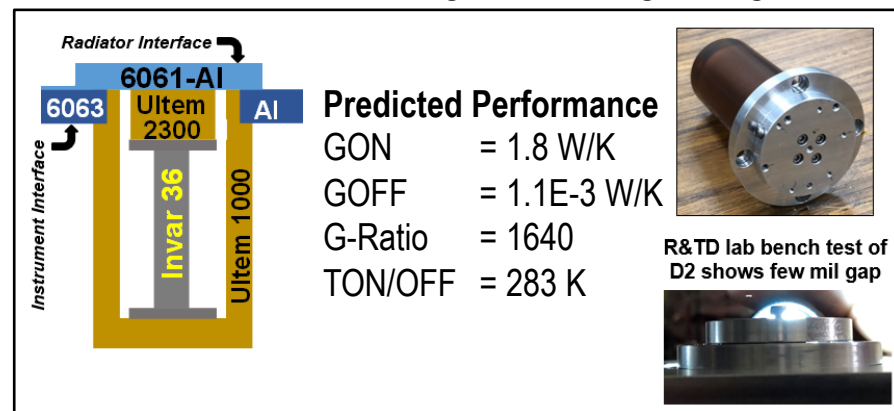
Thermal switch prototypes designed for flanged attachment to instrument enclosures, requiring 25-35 mm diam. opening so most of 80-130 mm length is inside; two 35-55 mm diam., 6 mm thick discs externally visible.

## DESIGN-1: Compact Mounting Flange

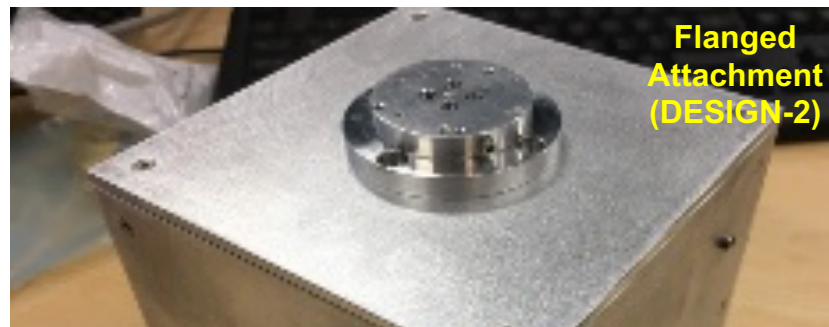


**Envelope:** Length = 126 mm, Max. Diameter = 35 mm  
**Mass:** 137 grams

## DESIGN-2: Heritage Mounting Flange



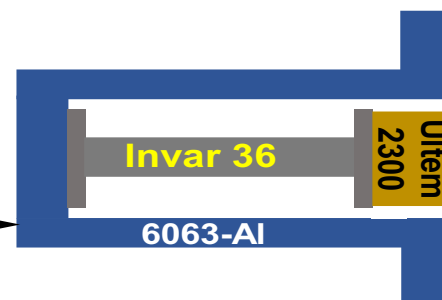
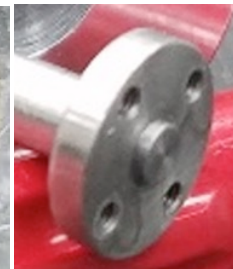
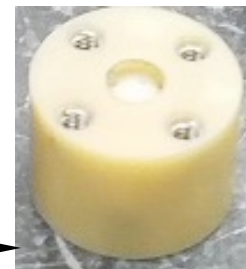
**Envelope:** Length = 86 mm, Max. Diameter = 55 mm  
**Mass:** 142 grams



# Fabrication

Conventional machining used except for mating surface preparation. For good ON performance, mating surfaces must be extremely smooth and highly parallel. A few key fabrication steps/features are indicated below.

- Mating surfaces hand-lapped and polished to ***near mirror finish***
- Bosses in Invar 36 and Ultem 2300 keep parts in stable position
- Machine, profile scan of rod on end-piece for parallelism, offset ( $\delta_1$ )
- Bellville washers (used on some previous DTE switches) ***not used***



Parallel to  
 $\lll 1$  mil

Parallel  
but out of  
plane  
(lower)  
by design  
offset ( $\delta_1$ )

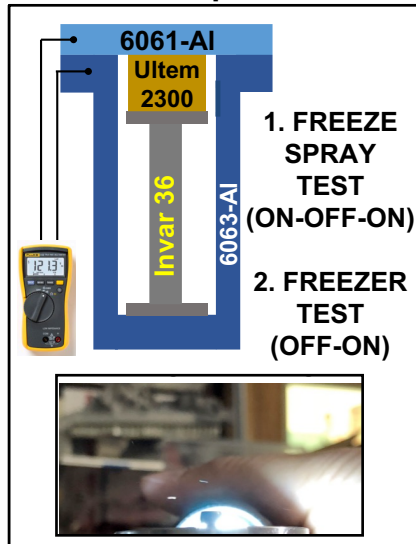




# Testing: Overview

**STEPS to TRL6:** (1) Benchtop actuation test (elec.); (2) TVAC  $G_{ON}/G_{OFF}$  and cycling test; (3) Vibration test with TVAC pre/post-test thermal; and (4) TVAC in relevant environment (hi-fidelity, long duration, model verif.).

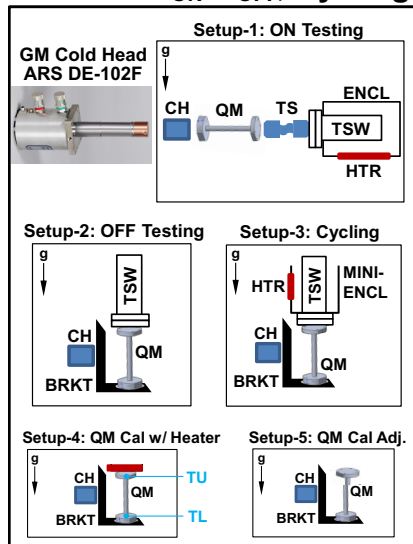
## 1. Benchtop Actuation



Mar 2018

**TRL3**

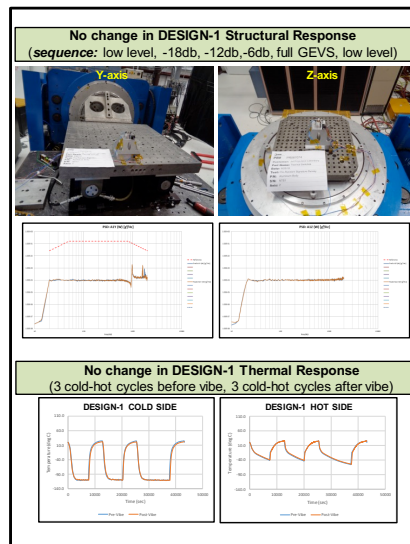
## 2. TVAC $G_{ON}/G_{OFF}$ Cycling



Apr 2018 – July 2018

**TRL3-4**

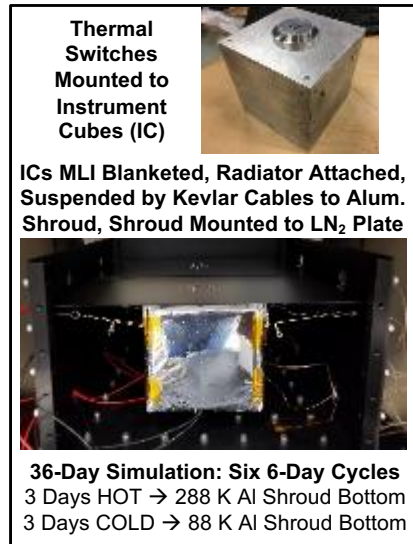
## 3. Vibe + TVAC Thermal



Sep 2018 – Oct 2018

**TRL4-5**

## 4. TVAC Rel. Environment

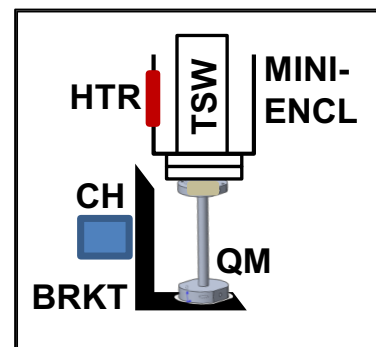
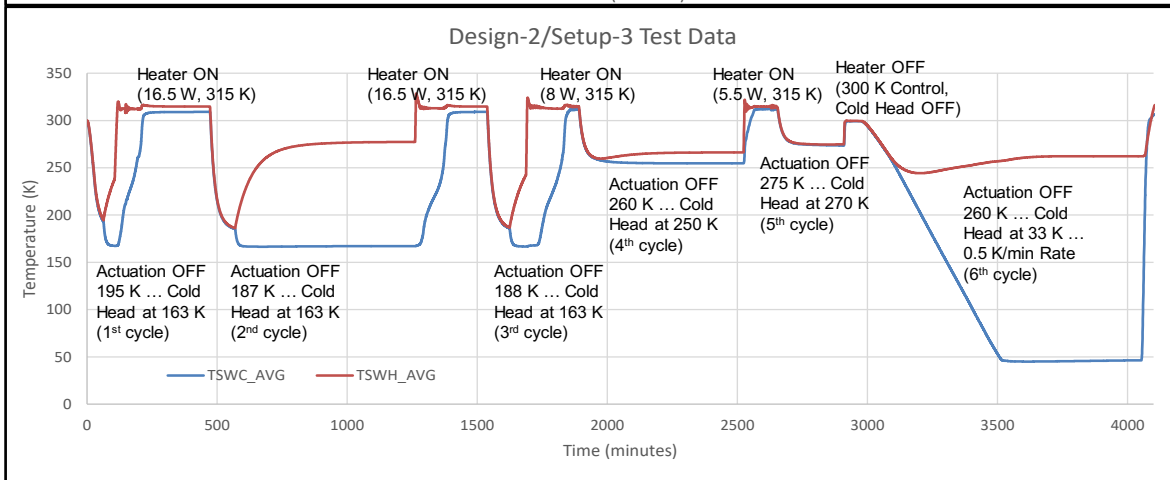
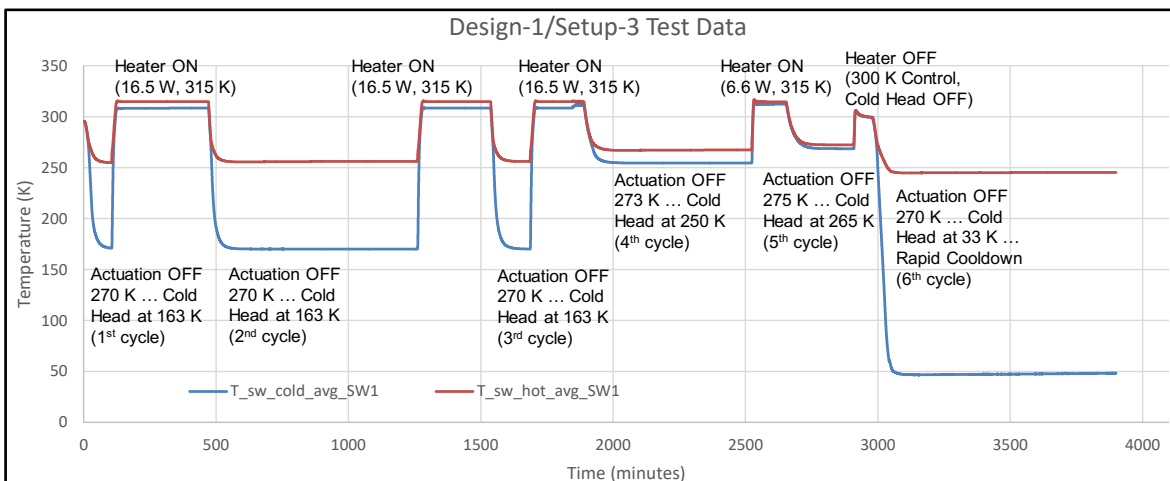


Dec 2018 – Jan 2019

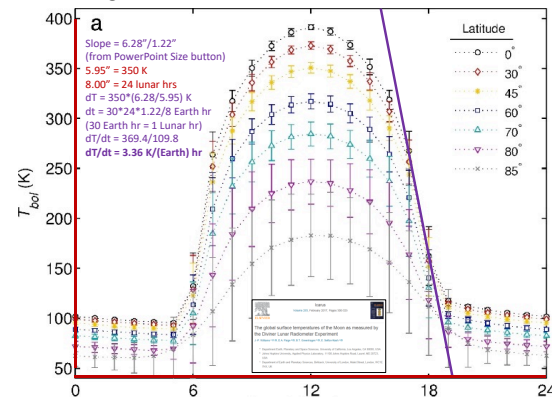
**TRL6**

# Testing: Step 2 Cycling

Cycling revealed that ON-to-OFF and OFF-to-ON actuation temps of Design-2 are sensitive to cooling/heating rate but those of Design-1 are not. On lunar surface, **rates are very low** so both prototypes are viable.



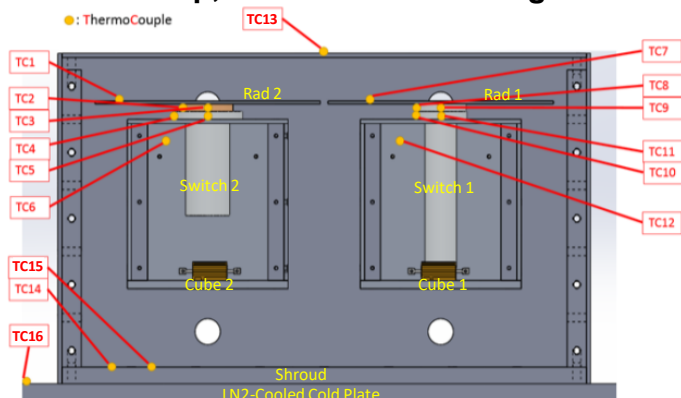
Lunar Surface Temperature Diviner Data  
Max Cooling Rate = 0.056 K/min ... so DESIGN-2 is Viable



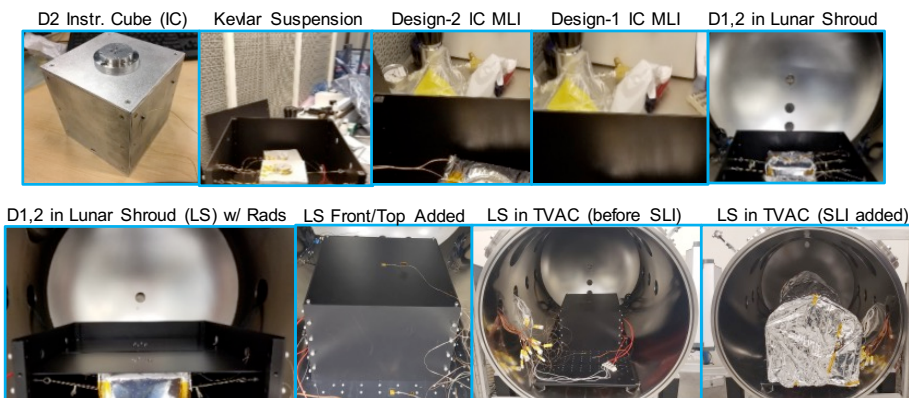
# Testing: Step 4 Summary

The Step 4 TVAC test showed that both thermal switches have highly repeatable, nearly identical ON/OFF performance. An exception to this is a 15 K  $\Delta T$  evident on 4<sup>th</sup> cold cycle that was not there on 6<sup>th</sup> cold cycle.

## Test Setup, Instrumentation Diagram



## Photos of Test Setup



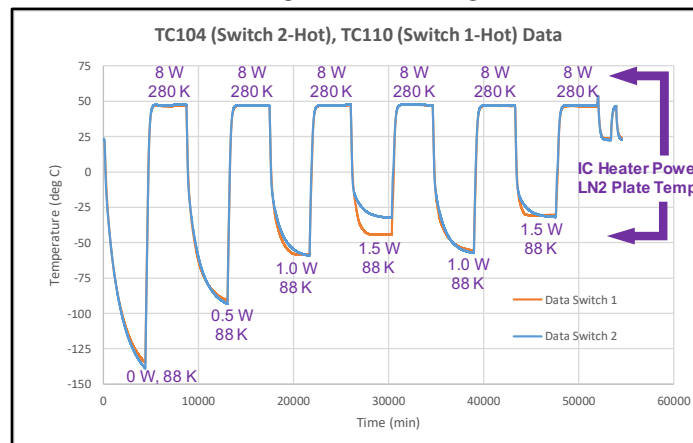
## Lunar Simulation Test Plan/Status

- **Six 3-day Cold Half-Cycles:** TLN2 plate = 88 K, IC Q = 0-1.5 W
- **Six 3-day Hot Half-Cycles:** TLN2 plate = 280 K, IC Q = 8 W
- **Total Test Duration:** 36 days (6 Six-Day Cold-Hot Full Cycles)
- **Lunar 30-Day Cycle:** Accelerated by 5X
- **Test Start Date/Time:** 11/30 at 11:40am (1<sup>st</sup> Cold Half Cycle)
- **Test End Date/Time:** 1/5 at 11:40am (end of 6<sup>th</sup> Hot Half Cycle)
- **Test Status:** **completed** (short 7<sup>th</sup> Hot Mini-Cycle added)

## Top-Level Summary/Assessment of Results

**Highly repeatable, predictable ON/OFF performance; few noted exceptions ...**  
During 4<sup>th</sup> cold cycle (1.5 W), Switch 1-Hot got about 15 K cooler vs. Switch 2-Hot. During 6<sup>th</sup> cold cycle (1.5 W), this effect was not observed in the data.  
Upon removal of setup, **one Switch 2, two Switch 1 Kevlar cables had broken.** Impact likely minimal (see photos later) but may explain 4<sup>th</sup> cold cycle anomaly if: Switch 1 cables broke separately: 1<sup>st</sup> caused side loads, 2<sup>nd</sup> eliminated them. Switch 2 more resistant to side loads, so single break was not a problem.

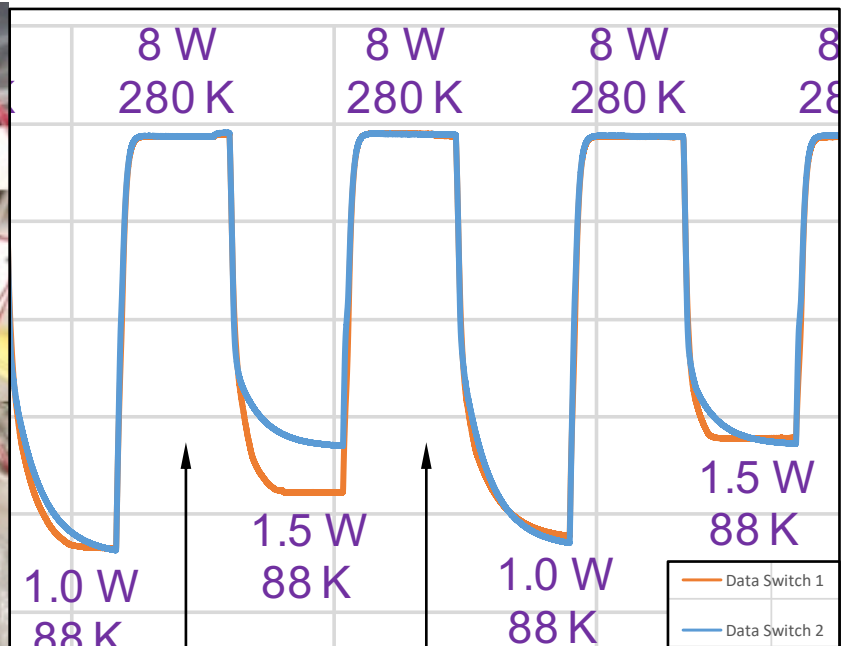
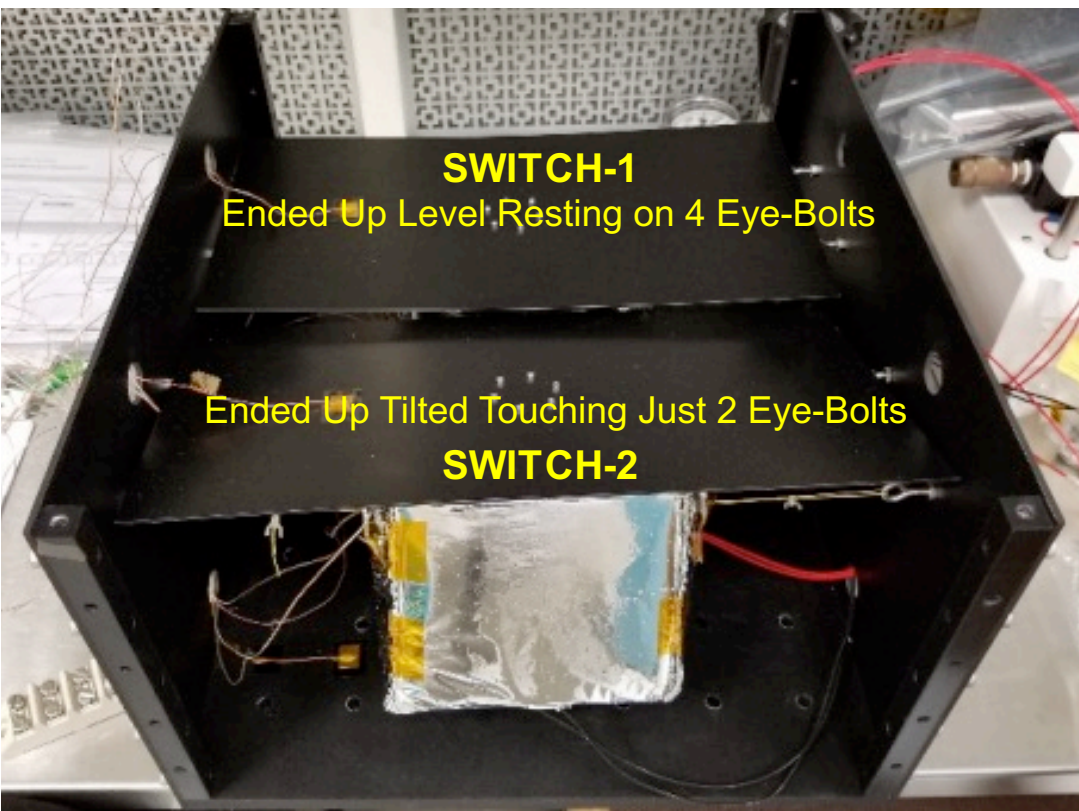
## Test Data: Design-1 vs. Design-2 Hot Side





# Testing: Step 4 Issue

Upon removal from TVAC, one Switch-2, two Switch-1 Kevlar cables had broken. Impact was minimal (see photo). It is theorized that the Switch-1 cables broke separately: 1<sup>st</sup> caused side loads, 2<sup>nd</sup> eliminated them. Switch-2 more resistant to side loads so single break was not problem.

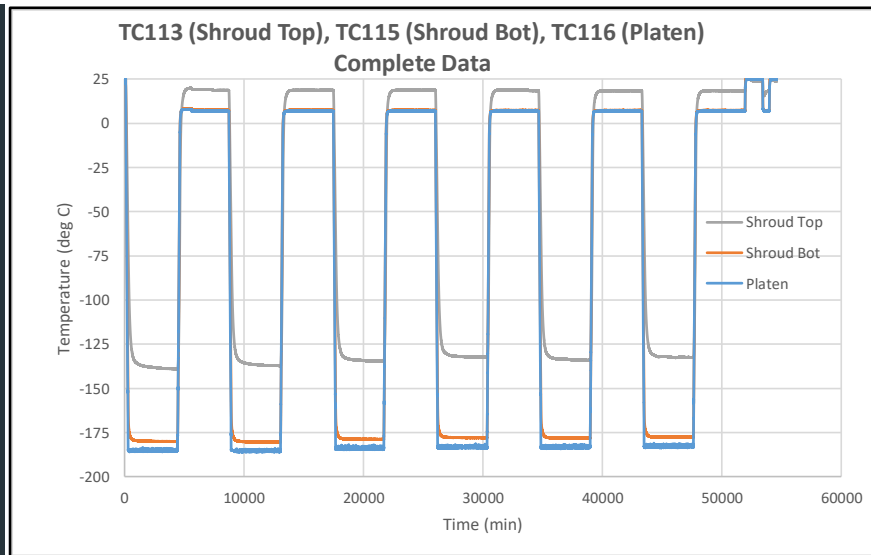
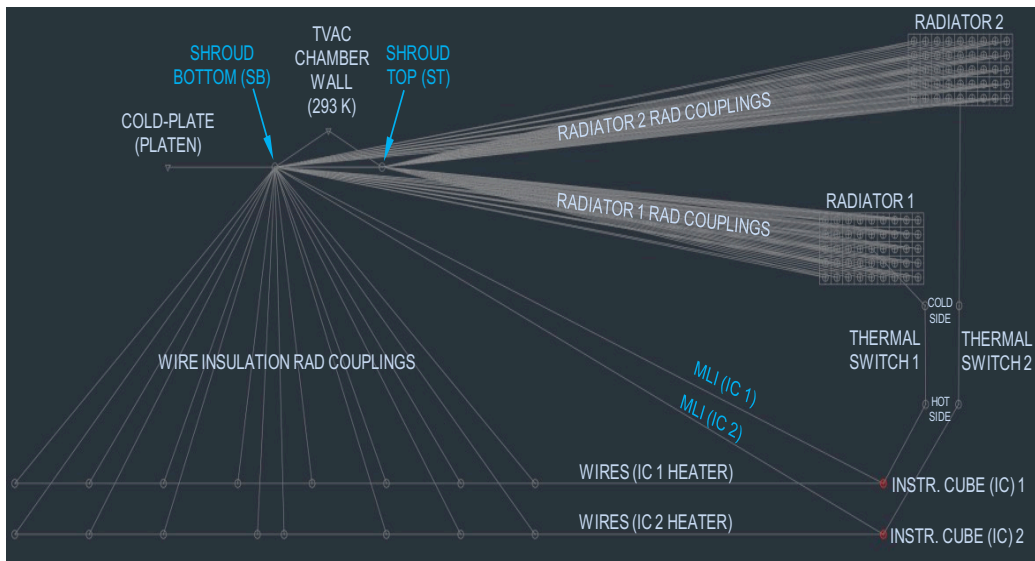


1<sup>st</sup> Switch-1 Cable  
Likely Broke Here

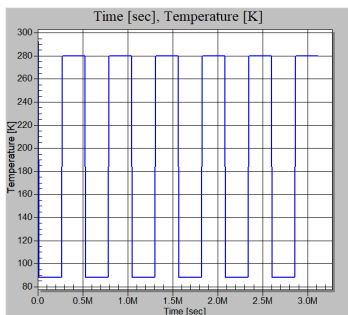
2<sup>nd</sup> Switch-1 Cable  
Likely Broke Here

# Testing: Step 4 Model

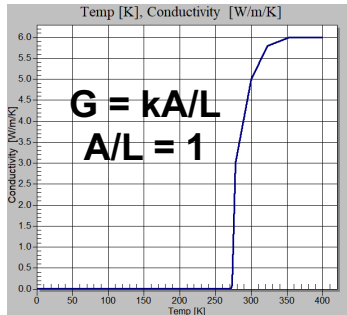
Test thermal model developed with just 3 correlating inputs ( $G_C$ ,  $G_R$ ,  $\epsilon^*$ ), where  $G_C$  = conductance from shroud top to bottom,  $G_R$  = radiative coupling from shroud top to bottom, and  $\epsilon^*$  = MLI effective emittance.



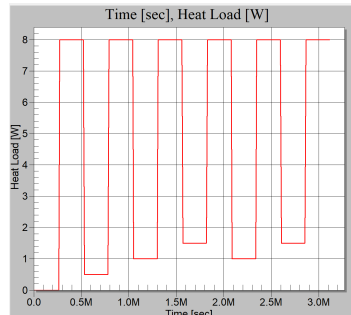
**COLD-PLATE (PLATEN) TEMPERATURE**



**THERMAL SWITCH CONDUCTIVITY VS TEMP**



**INSTRUMENT CUBE HEATER POWER**



## Correlated Model Inputs

$$G_C = 0.15 \text{ W/K}$$

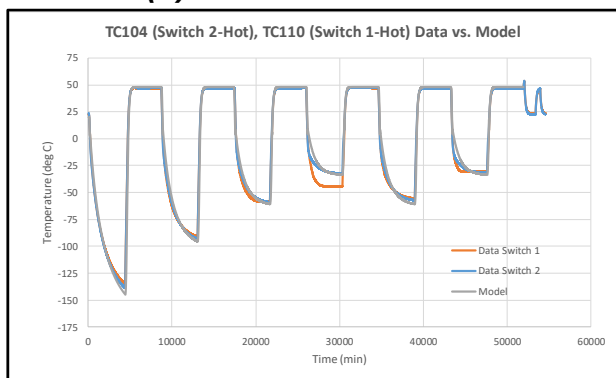
$$G_R = 0.13 \text{ m}^2$$

$$\epsilon^* = 0.04$$

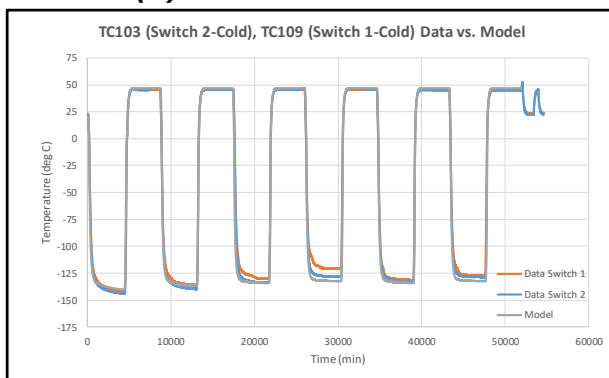
# Testing: Step 4 Data vs Model

Test thermal model results agree with measured data (except for cycle 4 issue) to within about 5 K over the entire system including: (a) switch hot side; (b) switch cold side; (c) radiator; (d) shroud top; (e) shroud bottom.

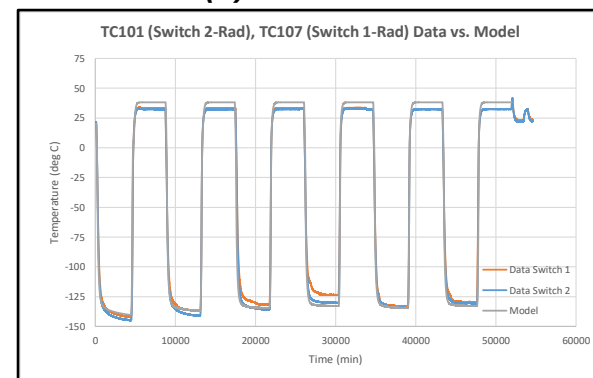
**(a) Switch Hot Side**



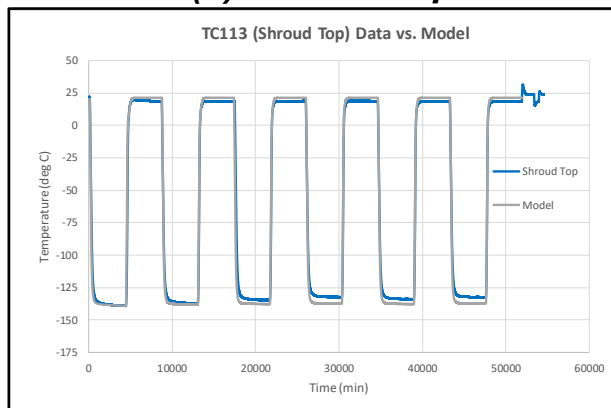
**(b) Switch Cold Side**



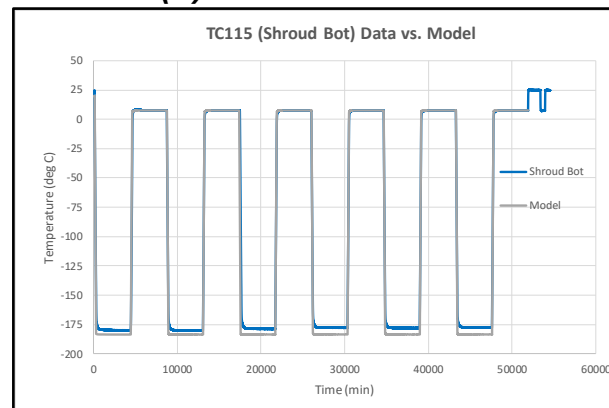
**(c) Radiator**



**(d) Shroud Top**



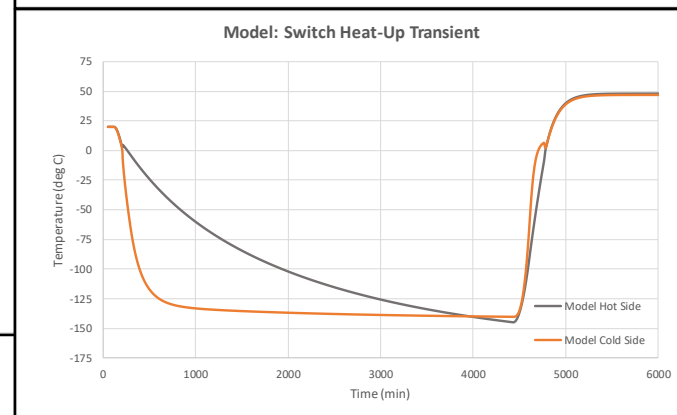
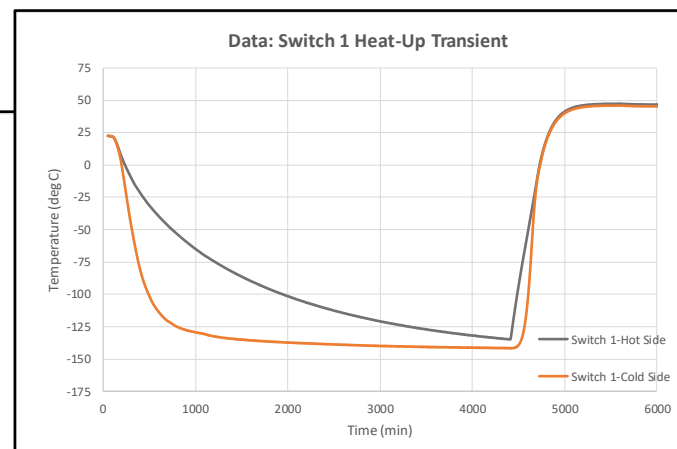
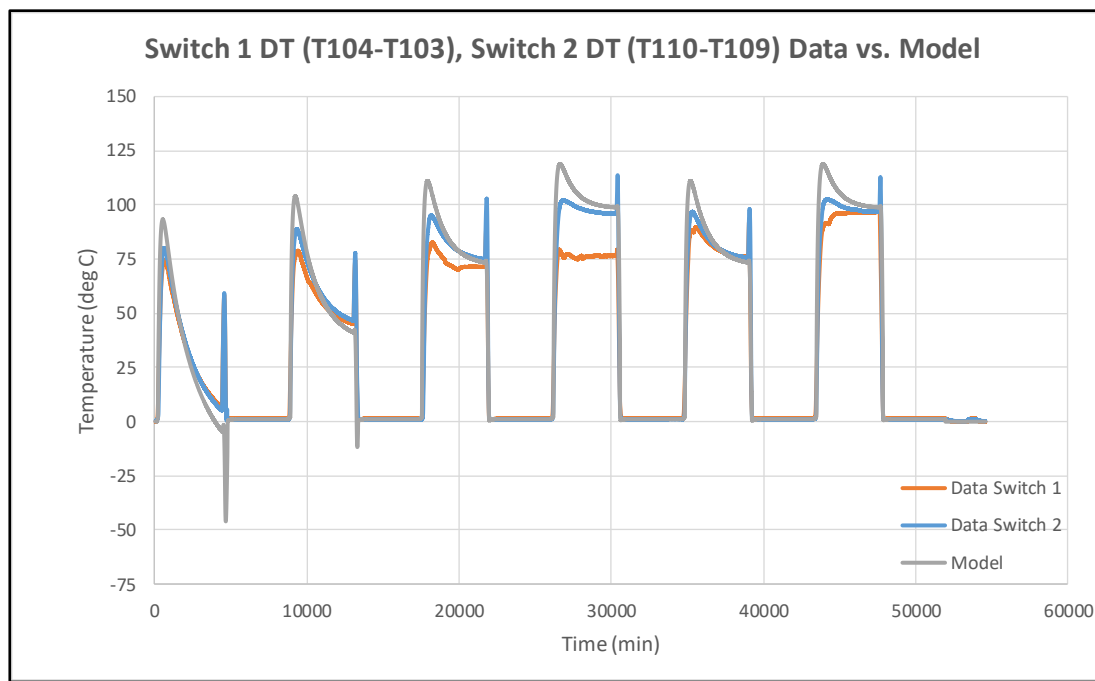
**(e) Shroud Bottom**





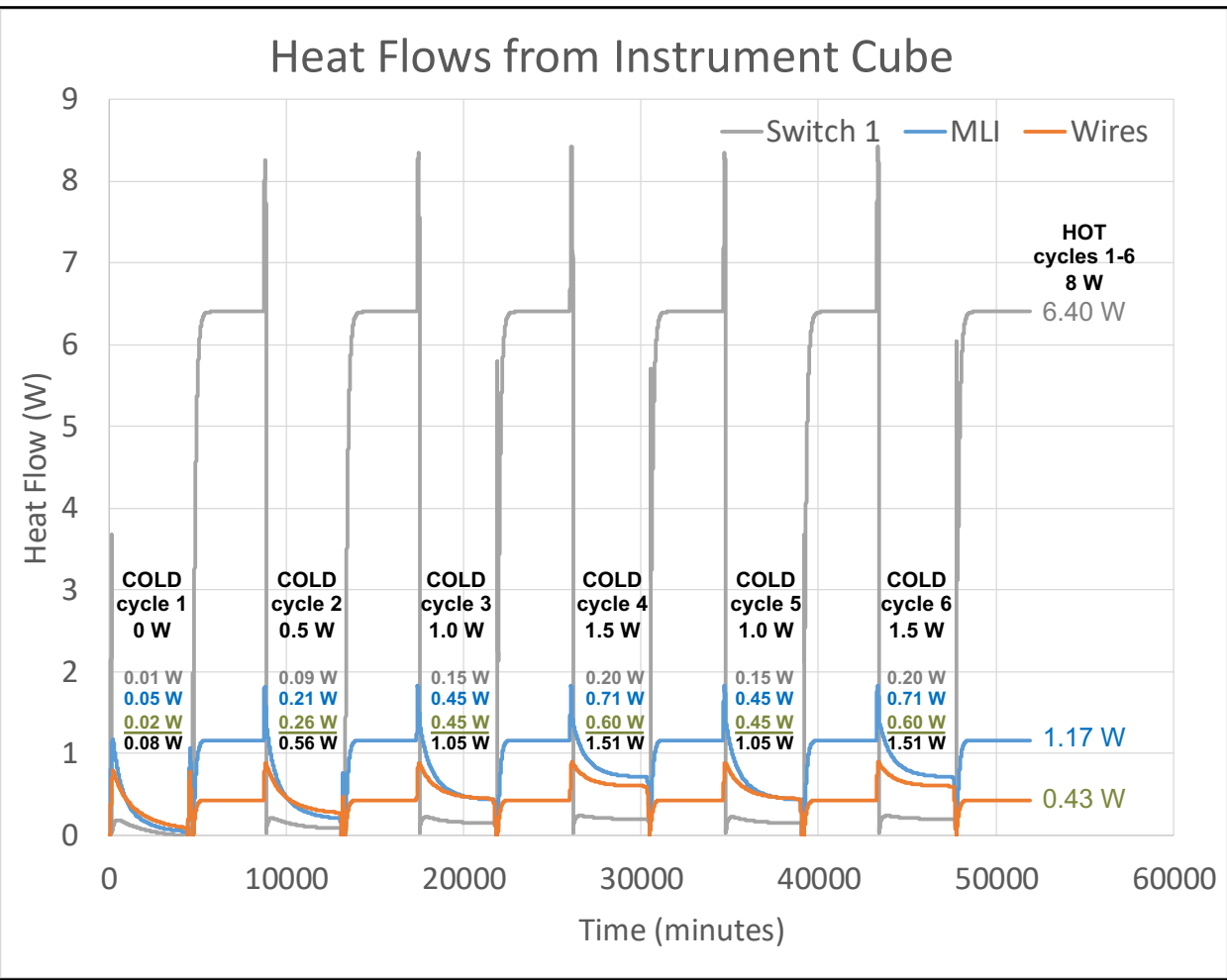
# Testing: Step 4 Data vs Model (cont'd)

The model predicts higher DT early in cold cycles but difference shrinks in time. By cold cycle end, model and data very close (except cycle 4). Large short-lived deviation occurs at start of each hot cycle as model cold side heats up faster than data (so data DT > 0, model DT < 0).



# Testing: Step 4 Model Heat Flows

Model used to predict heat flows via **switch vs MLI vs wires**. Results indicate where to focus effort in future lunar instrument thermal packages.



Assuming the thermal model is reasonably close to reality, **about 85% of the cold case heat loss in this test configuration was due to wires and MLI.**

These predictions underscore why future lunar instruments need the following (in addition to superior thermal switches):

- (1) High performance MLI
- (2) Isolative structural mounts
- (3) Low heat loss feed-throughs

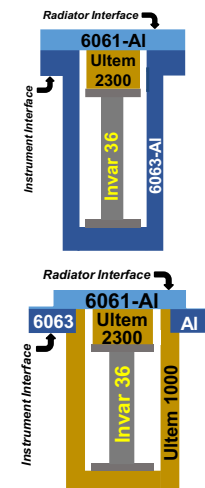
**NOTE:** Differences between applied power and heat flow totals due to IC not reaching complete steady-state (even after 3 days of cooling)

# Conclusion

- **JPL reverse-operation DTE thermal switch development and qualification test program has been successfully completed**
  - STEP 1 - Design/build/bench test (11/17 - 4/18)
  - STEP 2 - TVAC performance test (4/18 - 7/18)
  - STEP 3 - Vibration test (9/18 - 10/18)
  - STEP 4 - High fidelity (lunar sim) test (12/18 - 1/5)
- **Both JPL reverse-operation DTE thermal switch prototypes are at TRL6 based on completing all requirements in the table below**

**Table 3.1.3-1: TRL Definition and Decomposition by Factor**

TRL	Definition from NPR 7123.1e	Completion Criteria from NPR 7123.1e	Mission Req.	Performance/ Function	Fidelity of Analysis	Fidelity of Build	Level of Integration	Environment Verification
6	System/ subsystem model or prototype demonstrated in a relevant environment	Documented test performance demonstrating agreement with analytical predictions	Specific mission	Required functionality/ performance demonstrated	Medium fidelity: to predict key performance parameters and life limiting factors as a function of operational environments	High fidelity: prototype that addresses all critical scaling issues	Subsystem / System	Tested in relevant environments. Verify by test that the technology is resilient to the effects of life-limiting mechanisms
	✓	✓	✓	✓	✓	✓	✓	✓



- **Both JPL reverse-operation DTE thermal switch prototypes are ready for LITMUS or another comparable lunar flight experiment**





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Chuck Phillips

Jose Rivera

Rob Staehle

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